New time-of-flight system for the R^{3}B set-up *

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Introduction

The present LAND/R^{3}B experimental set-up can be used for identifying the reaction products up to the mass region ~ 150. At the future R^{3}B set-up at FAIR, this problem will be overcome, and also the reaction products in the mass region 200 will be effectively separated and it will be possible to identify them. On the other hand, extending the experimental capabilities to this mass region would also imply improvements in the time-of-flight (TOF) resolution. Identification of the reaction residues in high-energy nuclear collisions is usually based on energy-loss measurements and charge-particle deflection in the magnetic field. The mass-over-charge ratio can be calculated as: $A/Z = e/(m_0c) \cdot (B\rho)/(\beta\gamma)$. Once the nuclear charge is obtained from the energy-loss measurements, relative uncertainty in the mass determination can be calculated as: $\Delta A/A \approx \Delta(B\rho)/(B\rho) + \gamma^2 \cdot \Delta TOF/TOF$. The challenge is to separate neighboring masses in the mass region 200, where relative difference in mass between two neighboring nuclei amounts to $\sim 5 \cdot 10^{-3}$. Thus, in order to be able to separate neighboring masses, the relative uncertainty in mass must be of the order $2 \cdot 10^{-3}$ assuming 3σ precision. The magnetic rigidity can be obtained via particle tracking with a relative uncertainty of the order of 10^{-3}. In order to fulfil the demand on the mass resolution in the mass region 200 at $1A$GeV energy, the time-of-flight (TOF) has to be measured with a relative uncertainty better than $2.5 \cdot 10^{-4}$. Considering a flight path of ∼20m, this would mean that the ultimate TOF resolution should not exceed 20ps (sigma). While TOF is measured between two detectors giving start and stop signal, 20ps TOF resolution would mean that the time resolution Δt of each TOF detector should not exceed 15ps.

New TOF system

The new TOF system for the R^{3}B set-up will be based on the existing one but with improved capabilities. The start detector LOS will be made out of scintillator material, and will have dimensions of $55 \times 55 \times 0.5\,\mathrm{mm}^3$. The produced light will be collected directly, without any light guides, by 4 photomultipliers (PM). The PMs will be read out by a new multi-channel front-end card TAMEX developed by GSI CSEE group enabling high-resolution time measurements. The stop detector will be a multi-layer time-of-flight wall with high time and charge resolution and high-rate capabilities [1].

* Work supported by FAIR@GSI PSP code: 1.2.5.1.2.1.

In the following, we will discuss different effects influencing Δt and search for the compromise between best performance and costs. We will use the statistical method [2] for calculating Δt of a scintillator detector.

Calculations of the time resolution

There are different statistical processes which are limiting the attainable Δt of scintillation detectors: Time spread in the energy transfer to the optical levels of the scintillation crystal, decay time of the excited states, fluctuations in the propagation time of photons through the scintillation crystal, creation of photo-electrons within a photo-multiplier, as well as the associated electronics. The first application of the statistical model for calculating achievable Δt has been done by Post and Schiff [2]. At this place, we will not discuss the method in details but refere the reader to the paper of Post and Schiff. The advantage of this model is that all above-mentioned contributions can be studied and optimized separately, which is not always easy when using Monte-carlo simulations.
One of the important ingredients of the statistical model is the shape of the measured light pulse. This shape is of course influenced by different processes mentioned above. The primary shape is given by the light-production mechanism, and in case of plastic scintillator it has been shown [3] that the best-suited shape is given by a convolution of an exponential and a Gaussian function, so-called ExpGaussian [4]. In case of small-size scintillation detectors the light-production mechanism has a dominant role. For timing properties of larger-size detectors light transport becomes very important, and to consider this effect we have followed the work of ref. [5]. Knowing the light-pulse shape seen by a PM, using the statistical model we can calculate the contribution of the scintillator σ_{sci}. The contribution from the PM is determined by its transient-time-spread (tts) and can be calculated as: $\sigma_{PM} = tts/(2.35 \cdot \sqrt{R_{tot}})$, where R_{tot} is total number of photo-electron pulses. The contribution of electronics σ_{el} has been measured to amount to 8ps per readout channel. Then, the total Δt for each detector Δt_{det} can be calculated as: $\Delta t_{det} = \sqrt{\sigma_{sci}^2 + \sigma_{PM}^2 + \sigma_{el}^2}$.

LOS detector

For the LOS detector we have performed two sets of calculations assuming 1 AGeV ^{208}Pb ions passing through the detector:
1. Expensive solution: Consisting of the scintillator mate-

 doi:10.15120/GR-2014-1-FG-S-FRS-06

rial EJ232Q (rise time: 0.043ns, decay time: 0.608ns, light output: 19% of Anthracene) and a photomultiplier H6653 (tts: 0.16ns), see fig. 1.

2. Cost-effective solution: Consisting of the scintillator material EJ230 (rise time: 0.5ns, decay time: 1.5ns, light output: 64% of Anthracene) and a photomultiplier R9779 (tts: 0.25 ns), see fig. 2.

Fig. 1 shows that in case of the cost-expensive solution we can reach Δt of $\sim$4ps. In this case, Δt is determined only by the contribution from electronics. With the cost-effective solution, fig. 2, Δt is $\sim$8ps, but in this case Δt is given by the scintillator material. In both cases, the contribution of the photomultiplier, due to a large number of produced photoelectrons, is negligible. First tests with a

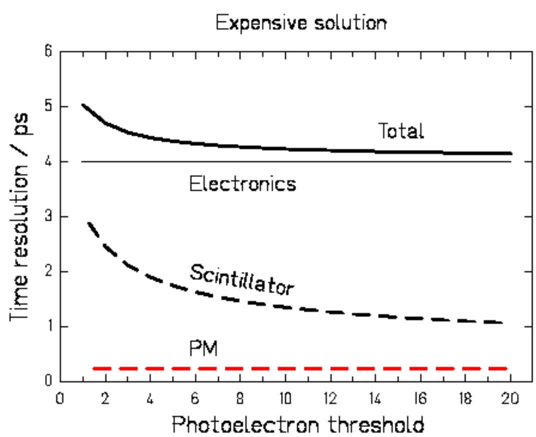

Figure 1: Contribution of different components to Δt of the LOS detector for the design option (1), see text.

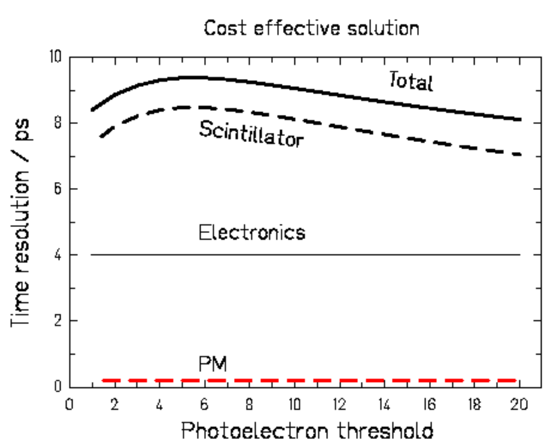

Figure 2: Contribution of different components to Δt of the LOS detector for the design option (2), see text.

Nitrogen UV laser have been performed, see [6].

New TOF wall detector

In the case of the new TOF wall we have assumed that the detector consists of 4 layers of EJ200 scintillator material (rise time: 0.9ns, decay time: 2.1ns, light output: 64% of Anthracene) and that the signals are read by R8619-20 photomultipliers (tts: 1.2ns). We have also assumed that 1 AGeV ^{208}Pb ions are passing through the detector. The results are shown in fig. 3. Also in case of the new TOF wall

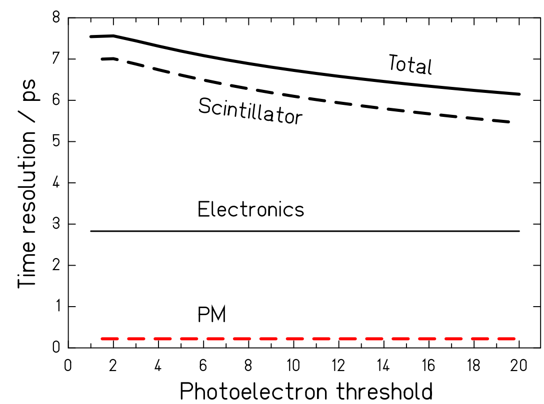

Figure 3: Contribution of different components to Δt of the new TOF wall detector.

the contribution of the PMs to the total Δt is negligible. Total Δt well below 15ps can be reached, and is mostly determined by the scintillator material. The use of more expensive PMs or scintillator materials is thus not needed.

Summary and outlook

Needed Δt of TOF start and stop detectors of 15ps can be reach. In case of the new TOF wall Δt is $\sim$8ps due to several-layers design. In case of the LOS detector, with a cost-effective solution Δt is $\sim$8ps, and thus well below 15ps. With the expensive solution, we could even reach Δt of 4ps. In 2014 prototypes of both detectors will be tested and results will be compared with present calculations.

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doi:10.15120/GR-2014-1-FG-S-FRS-06